Engineering Thermodynamics
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Week-10
Lecture-45
Vapor Power Cycle

Welcome to the lecture on Vapor Power Cycle. In this, we will talk about the origin of Vapor Power Cycles, and how to do cogeneration and second law analysis, and how to combine your ranking power cycle with your gas power cycle, which we discussed earlier, to make a combined cycle. After that, we will discuss. So, we learned in the last lecture how to work on high pressure boiler, how to reduce moisture content at turbine exit by using reheat. Now we will talk about Regenerative Ranking Cycle. We have to handle one more issue. If we look here, we know that if the average temperature is high, where we put heat, then the efficiency increases. But in this case, the diagram you see, this part is a low temperature addition, The question is, if you increase this particular part, how to increase it? So, one way is that the 2 to 2' is at low temperature, because of which the average temperature is reduced, because of which the cycle efficiency decreases. To do this, you have some options. The steam is coming out of the pump, you can use the steam to complete the turbine and then you can use it to heat it. This is called regeneration or feed water heating. So, what I mean to say is that the steam that is coming out of the pump, you can leak some parts of it. and this is the pump that is coming out of the pump you can exchange these two with heat transfer which you can do in two ways one is open feed water where it is mixed and close feed water where So, there are two advantages of this. First, it is because it goes on high temperature, then the corrosion on the boiler will be reduced because it removes the leak in this process.

Second, this feed water heat, as I said, we can mix it in two ways. First, open feed water heat, in which you will have a physical mixing. and the second is without mixing So this process is called open feed water heater Let's take an example In this, literally your mixing is happening So as I said that some of the pump's exit to that will mix with some parts of the turbine So let's take an exit of the turbine which is 6 Here it is mixing with open feed water open water heater and the exit here goes to the other pump which means you have two pumps because of increasing the temperature and finally it goes to the 4th pump if you see the diagram So this is 1, which is coming out of the condenser exit. This is 2, which is the first pump. So here the work is done. In. One This pump is in 1. Here, from 2, your mix is on 6. Pay attention, 6 and 2 are mixed. Due to which it finally comes to 3. So, this is 3. And after 3, there is a pump. So, this is your W pump 2. So finally, we got 4. 4 is actually the boiler. This is the P boiler. It enters at the pressure of the boiler. The boiler hits T5. Here it goes to the turbine. So, there is a leak in the turbine. Here is 6 which is at low pressure. but on medium pressure here it is 6 the temperature is higher and the rest of the rest of the it expands it literally expands further and later the condenser the inlet is made on the condenser which is condensed and comes to 1 so this is how your cycle is done 6 will have some mass fraction because some of the parts are in 6 and some are in 7 So the mass fraction is 6 the rate divided by 5 is W so this is the mass fraction so Y fraction is used in 6 so this is Y fraction you can also get this from this how much work is out of the turbine we will talk about that later first notice that both are ideal there is an internal reversible condition in this too and W power pump in here W will be used for V1 and delta P1 delta P will be P2 minus P1 and here w2 is v3 for p4 minus p3 as I have written here now apart from this you have to see where is the Qin is naturally this only one Qin here main actual Qin which is h5 by h4 and where is the Qout is But here, since the fraction is less, and we are talking about mass per unit, the equations of mass per unit are written, and the fraction is written here. So Qout is not 1, it is not H7 minus H1, it is multiplied by mass fraction, which is more, which is 1 minus Y. So you can actually take this out, you can also assume that this is M5, and finally you will get all the parameters so this is the key out and there are two parts in W turbine you can take out W turbine out and you can also take out HM out 5 h5 over minus m dot 5 y h6 plus m dot 5 y h7 so you can't even say that this is actually this in fact this is the same thing it has been rearranged a little bit h5 minus h6 which is plus Because you have to do the total work, this part is defined by definition, but since it is a flow work, you have to do it naturally, how much will be the total work. Because here, the total mass flow rate will be same as the m dot 5 here, that will be exactly the same here, but since these two are divided, the work here is also going to be in fractions. So, that's why 1-YWPin is the contribution of total work in and plus WP2in So, this is the total work pump in and according to this you can calculate the efficiency and other things, so this was your open feed water heater. If it is closed feed water heater, then the other things are the same. But this thing will come here that this heat exchange has not been done in the form of mixing.

$$w_{pump\ 1,in} = v_1(P_2 - P_1)$$

$$w_{pump\ 2,in} = v_1(P_4 - P_3)$$

$$y = \frac{\dot{m}_6}{\dot{m}_5}$$

$$q_{in} = h_5 - h_4$$

$$q_{out} = (1 - y)(h_7 - h_1)$$

$$w_{turb,out} = (h_5 - h_6) + (1 - y)(h_6 - h_7)$$

$$w_{pump,in} = (1 - y)w_{pump\ 1,in} + w_{pump\ 2,in}$$

$$w_{T,out} = \dot{m}_5 h_5 - [\dot{m}_5 y h_6 + \dot{m}_5(1 - y)h_7]$$

It is here. Here your leak is at 7, which is from the turbine, which is at medium temperature and pressure. and the condenser which is at low pressure here, it gets mixed here so you can see it like this, here we have 8 inputs on the condenser this condenser is 1, 1 goes to the pump, 2 goes out of the pump and after going out of the pump, after mixing here, you have 2 streams one which is mixing, mixing goes to the chamber and the second goes back to the pump, then it goes to high pressure and mix it properly. Here it is properly mixed. So, you can see the form of the T-S diagram in this form. So, you can make such a process. Here it is just that both are at different pressures, so they are not mixing. And finally, here we are trying to make the same pressure in the stream. So, this pump 2 brings you to 3 to 4, which means that you are mixing properly. 4 or

5 are at the same pressure. So, you can make such a diagram and make it more complicated to increase efficiency. The main purpose is that we can understand that such processes exist. And to understand more complicated and real processes, we can understand it with some examples, but our purpose is to expose it so that you can understand it. So, we will not complicate it much, but we will have to give some examples to appreciate it and praise it. How this design has changed in so many years. and number of devices are added. We will talk about open feed water heaters. As I said, in the open, the pressure will be the same. Wherever there is mixing, the pressure will be same. Here also mixing is done later, but the pressure is same. For that, pump 2 is done. In the open, the pressure is same. Whatever leak we are doing from turbine, the pressure is the same as the pressure of pump 1 this is your steam power plant which is an ideal regenerative ranking cycle open field water heater steam enters the turbine at 15 MPa and 600 degree Celsius and condenses at 10 KPa some steam comes out at 1.2 MPa and feed water heater because of same pressure pump 2 pressure is 1.2 MPa and when it comes out again it is 1.2 MPa and when it goes to 3 MPa and from other pump it is 15 MPa which is the pressure of boiler so this is your overall process diagram and process design and corresponding temperature vs that one is your inlet in pump one from one you have brought it to 2 which is at 1.2 Mpa and this is at 15 Mpa where your boiler works condenser is at 10 KPa so from one to two you have taken it hit it from 2 you mixed it from 2 to 2 and 6 then you got point 3 which will bring the feed back to the boiler so here the inlet worked and naturally your combined WTA so the fraction of steam that is being extracted from the turbine means we have to extract how much is y and we have to extract it from the thermal efficiency heat up. So, we have two questions now, let's try to solve them. The other conditions are the same as the first one. It is ideal that there is no pressure drop. It has isentropic, the rest is the pump and turbine. It is an isentropic process. And boiler, condenser, feed water, there is no pressure drop anywhere in these places. So, these are all the ideal conditions. Now we will see that to get all this information, we will need information for the questions that we have asked. State 1. P1 is equal to 10 kPa 10 kPa and this is your saturated liquid So this is its corresponding H1 which is HF at 10 kPa and V1 will come V1 at 10 kPa state 2 is given by pressure 2 1.2 MPa entropy is fixed it is an isentropic process and we can directly remove its enthalpy because H2 is equal to H1 plus H2 is equal to H1 plus W pump So, 1 will come, because it is 1, so 1 will come. So, this is your pump 1. This is your V1 P2 by minus P1. So, from here you will get information. So, you know P2, P1, V1, so you got S2. So, you know S2, S1, V1, you know this from the table. So, you can get this information from the table. Now, let's come to stage 3. I am not taking out all the values. If you understand the process, you can do it easily. In state 3, you know the pressure, P3. P3 is 1.2 MPa. And this is your saturated liquid. This condition is here. It is saturated liquid. As we have shown here. Now from here, Basically you will get the information because V3 is VF at 1.2 MPa and H3 is HF at 1.2 MPa Let's talk about state 4, again it was sent to the pump See here Open feed water was sent to the pump So from here You will take P4 which is 15 Mbps which is finally your P4 15 Mbps and S4 is S3 and you can get this out of the alarm this is an isentropic process so W pump 2 is V3 P4 minus P3 which you can get out because V3 knows, P4 knows, P3 knows You can also remove H4, H3 plus WPE2 because you know S3 So you have all the information of 1, 2, 3, 4 Rest of the information is left of state 5 State 5 has P5 15 MPa Now this is the super-critical, super-heated stream. So, from here you will get table 6, from here you will get H5 and S5. Then comes your state 6. State 6 is your P6, 1.2 MPa. And since this is isentropic, S6 is equal to S5. Here you will see the data. If you go to the superheated, you will get S5 and S6 more than the corresponding 1.2 Mpa. So according to that, you see where the table fits. So T6 will be found at 218.4 degrees

Celsius. Then comes your state 7 Here it is 10kPa Which is, P7 And you know that S7 is equal to S5 from here you will get the quality The quality is S7 minus Sg This is Sg and Sfg where is it from? This is 10kPa So from here you will get the quality Which is 0.8041 And from here you will get HF from here you will extract h which is hf plus x7 hfg so from here it is extracted so this is h7 so from this way you have got all the information now what you have to extract you have to extract y value To find out the y value, you can take out the energy balance of the mix.

You can take out the energy balance of the mix or the energy balance of the mixing. The best option is to take out the energy balance of the mixing because it will contain complete information. There is no work involved in mixing. So, if there is any work involved in mixing, there is no work involved in mixing. and if there is no additional heat transfer then E in is equal to E out so if we apply mixing on the device on the feed water heater then if you apply this on the open feed water heater then open feed water heater. So, if we do E in is equal to E out, then this will result in summation m dot in is equal to summation dot n out. Because generally we will say that this is insulated. So, in such cases, we will assume that the other things are zero. So, if we do it on feed water, then what is in the inlet here? In the Inlet, there are 6 and 2, in the Outlet there are 3 So this will come out y, if we assume that this part is y There is y fraction in it And we are taking the unit term in the pi unit So y times h of 6 plus 1 minus y times h of 2 Which will come out from here It comes out from 2, so this is Y and this is 1 minus y And This will be the total of H3 Since it is 1, the part that is connected to the other will be 1 So part will go to H6, 1 minus y part will go to H2 And the rest will be left When we get it later, then H3 will come out So that's why it has 1 here This is how it could have been written Y plus 1 minus Y Okay? So this will be 1, so this is H3. So, y H6 plus 1 minus y H2, this is your H3. Now from here you can get y. y will be your H3 minus H2 divided by H6 minus H2. So, this is the information that you have taken out. So, from here it will be 0.2270. Now the question is how to get eta? Eta is 1 minus Qout divided by Qin Qout is 1minus H5 minus H4. Qout is condenser is Qout is actually H7 minus H1 So this will be 7 minus H11 so we write h7 minus h1 multiplied by fraction 1 minus y and qin is h5 minus h4 so qin is h5 minus h4 and qout is 1 minus y multiplied by H7 minus H1 So we have put this here So we have got this information and also got y So we will get 46.3% in eta So If we analyze properly So what happens with this is that the regeneration we have done here because in this we have regenerated according to open field water with which this temperature It is better to check the previous work out and check the results. compared to what you have done and what has been specifically reduced.

In fact, it is also possible that heat input has effectively reduced. We can do all this analysis because we will not be able to do so much discussion in this lecture. But my suggestion is that you see all these things and see carefully how valuable this regeneration is. Because what happens in this is that your work the output is reduced but the heat input is also reduced which increases the efficiency and as the additional 3% is increasing then also it is a valuable addition in this process because the utility of this is very high in your industry Now, it is important to note that the assumption we took was in the ideal ranking cycle which internally we consider reversible and that is why you can do second law analysis and see that in the actual ranking cycle in which there is reversibility where ever you get heat or mass flow, there will be reversibility so you can remove it, exergy, destruction, steady state flow, balance it You can add extra distortion or even bridge insertion where S out is assessing and these two terms can be added where your mass flow or boundary is happening. You can also take out per unit mass. So, you can also do analysis with this which device you have to think more about how to make it efficient. So, this is a general analysis. Normally, you will see that wherever the heat is transferred from high to low temperature, there will be a tendency of excessive destruction. So, we can apply for it. As we said here, in this case, if we are talking about the cycle, then this will be used. If there is only one source and one sink, then this will be used. Stream Energy definition is what we are doing now. So, in general, we can analyze where is the most irreversibility and where we can improve. So, exergy destructions are normally dependent on magnitude of heat transfer. How much amount of heat we have transferred and on high or low. This is important because it depends on Q and of course, The boundaries are also dependent on this. But in general, it will be important that there are a number of cues, so you can also modulate it and see the other conditions.

Exergy destruction for a stedy-flow system,

$$\dot{X}_{dest} = T_0\dot{S}_{gen} = T_0\left(\dot{S}_{out} - \dot{S}_{in}\right) = T_0(\sum_{out} \dot{m}\,s + \frac{\dot{Q}_{out}}{T_{b,out}} - \sum_{in} \dot{m}\,s - \frac{\dot{Q}_{in}}{T_{b,in}}$$

$$x_{dest} = T_0S_{gen} = T_0(s_e - s_i + \frac{q_{out}}{T_{b,out}} - \frac{q_{in}}{T_{b,in}})$$

Exergy destruction of a cycle,

$$x_{dest} = T_0(\sum \frac{q_{out}}{T_{b,out}} - \sum \frac{q_{in}}{T_{b,in}})$$

For cycle with heat transfer only with a source and a sink

$$x_{dest} = T_0(\frac{q_{out}}{T_L} - \frac{q_{in}}{T_H})$$

Stream exergy

$$\Psi = (\mathrm{h} - h_0) - T_0(s - s_0) + \frac{v^2}{2} + gz$$

So, we will not do any example on this, because it will be a long exercise for video lecture. But you can see in the book that there is an example, so you can read it and understand how to do the exercise analysis. in such regenerative power cycles or in general power cycles. In industry, like chemical, pump, paper, oil production, refining, steel making, food processing, textile, in this, many requirements, important is that we need energy input, which is called process heat. It is not necessary that we have to boil it. In all these industries, we just need heat in some form, which is needed by the process. And this process of heat is required between 5-7 atmosphere or 150-200 degree Celsius. So, it is not very high. As we have seen, the boiler is running in mega Pascal, or the temperature goes up to 600 degrees. So, it is not that high. That is why we transfer this heat through steam. Whether it is by burning oil, coal or natural gas. So that is why It is very common sense, it seems like a very casky, which is already being made in our system, the way we waste heat, why not use it? Why not use the heat that is being loosed, like it came out of the boiler, we leave a lot of condenses, why not take out some heat and use it? As it is written here, boiler is a process, heater is a process, which brings the process to a condition, and this Of course, the temperature will be less than the typical use of a boiler in a vapor power cycle. But this heat is very useful.

We call this heat process heat because it is sufficient heat that is useful in many industries. So, this idea has become the concept of cogeneration. They also meet the process heat requirement.

And that is why their excess heat or intermediate or whatever is there, this is your core generation plant. So, what is in it, your requirements are added to it from one source of energy to another. So, if you think about this concept, then if we are a turbine, This is the boiler that goes into the turbine and expands to the condenser. Condensers are usually used to measure heat loss. But if we consider this, we can use some parts of the loss. 100 kW of it can be processed heat in the sense, we can work on low temperature and condition we can use it so if we use it like this, then we can use 100 kW of work or energy and apart from this, what is your turbine? so if we see, we can get 120 kW of it so it can be 100% efficient also okay so if we see like this 100kW is useful, finally you use it but it is heat, you can use it with heat exchanger or any other form but this system is giving, not wasting 100kW The actual cogeneration plant is 80% utilization factor of this is called as Net power output plus process heat delivered divided by total heat input So in this Wnet plus Qp is there plus divided by Qin which is Qin. So, this is your utilization factor. So, this way you can co-generate it. This is the concept. Now if you look at it carefully, sometimes steam power plants can be made, sometimes it can effectively co-generate. So how can we do this? This is a cogeneration plant with adjustable load. The load can be changed anytime. So, where there is a high process heat requirement, sometimes the steam is given more in the process heating unit and not at all to the condenser. So, in this case, what we did is we showed here that this is a process heater, but there must be some condenser if you want to make a steam power plant. So, as you can see, this is a turbine, which produces a stream that is getting process heat. The second part is going to the condenser. So, if we want the entire process heat, then the condenser mass is zeroed out. In this case, the waste heat is zeroed out. The rest of the heat that is going to the turbine is going to the process heat. And the process heat is going to the pump. The pump is being used somewhere due to the process heat. So, this is the purpose of this. And this is how your complete cycle is made. If this is not sufficient, then some teams go to the boiler i.e. the process heat used at low pressure and temperature is not sufficient So what we do is, some teams go to the expansion wall from the boiler and this is your expansion, the pressure is reduced and this way your process heat goes to the boiler So this is one way, this is a direct process heating Maximum process heating occurs when the steam leaving the boiler completely passes through the expansion. That means m5 will become m4. In this condition, the maximum process heating unit occurs. In this condition, the power produced becomes zero. where there is no demand in process heat, in that situation, your m5 is zeroed, this becomes zero and m6 is also zeroed, this also becomes zero, so this becomes your ordinary steam power plant. So, this is a process which you can understand. In this, you can also take energy balance, for example, Q in will be the same which is more here, m3 multiplied by h4 minus s3 Q out What is happening is happening from here m dot 7 s7 minus s6 Qp Which is your process heat is emitting M dot5h5 plus M dot 6H5 other than that, this heat is emitting through heat exchanger or any other form this much energy is emitting through Q dot P in process heat unit and finally, the work of turbine is As we did before, it will be in the same form. H4 minus H6 M4 minus M5 This will be in this part. Plus M dot 7 H6 minus H5 You can also write this in the form of mass fraction as we wrote before. So h4 minus h6 is this part h4 minus h6 multiplied by the fraction which is m dot 4 minus m dot 5 plus m dot 7 and note that m dot 4 is m dot 6 plus m dot 7 plus m dot 5 like this You can also do mass balance properly and do analysis on it. So, the last concept we try to understand. There are two things in this, the popular modification that has been done in the gas power cycle. In this, since it works in different conditions, it is at a high temperature pressure. This combination is called combined gas-vapor cycle. It is of great interest in the industry to use it because it increases thermal efficiency. So, the ideal is that gas cycle and to use the Vapor Cycle.

This concept is becoming very popular. The important thing is that the concept is not increasing the cost. In general, the new power plant is trying to combine the existing steam and grass power plant and make a cycle power plant. This is a combined gas vapor cycle. Notice how it is done. As we talked about the turbine, there will be a compressor of air. Which compresses it at high pressure. After that, it gets compressed and operates at high temperature and pressure on the gas turbine. Here we are using a heat exchanger which works like a boiler in steam vapor power cycle. Here it works like a heat exchanger, and it is maintained at high temperature which is maintained at constant pressure. We are interested in maintaining the heat exchanger from 2 to 3 and 2 is this and 3 is this. 8 is used and 9 is used for the exit. The gas that is coming out is losing its energy and the whole energy is being used to boil the steam. This combined form in which we have used gas to steam is called the combined gas whipper cycle. This is already in the existing plant and how it is connected. Instead of throwing it away, we will use it as a cogeneration. This is the concept, and it is the result of sustainable power plant and engineering. Today we have to think about how to make the minimum energy waste as good as possible. So, I hope you understood this whole Vapor Cycle, in which we started to understand what Carnot will do, and then we discussed how the ranking cycle is ideal for Vapor Power Cycle. Then we discussed that it can be a division because irreversibility exists, and how we can increase the efficiency of the ranking cycle, and then we discussed what is the concept of reheat, how we have used boiler high, post pressure, we discussed about the use of two or one reheat stage. Then we discussed about regenerative ranking cycle to increase the average temperature. That means the temperature of the pump can be increased before the boiler enters. So, the concept came for open feed water and closed feed water. We said that it is a cogeneration, and you can also analyze it with the second law of analysis that which part of the process is not efficient. And then we asked how the existing gas and power cycle can be combined and how can a combined gas and vapor power cycle be made, which is very popular nowadays and whose efficiency is more than 50%. So, I hope you understood this concept and the problem solving that we did. I will also suggest you follow some examples of the test book so that you can understand it better because you need to practice it So we will start a new topic in the next lecture and then we will meet in the next lecture till then I take your leave, bye